D'GROOVE: A HAPTIC TURNTABLE FOR DIGITAL AUDIO CONTROL

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ABSTRACT

In this paper, we discuss the design and implementation of D'Groove, an intelligent Disc Jockey (DJ) system that uses a haptic turntable for controlling the playback of digital audio.

We begin by describing the tasks of a DJ and defining some of the challenges associated with the traditional DJ process. We then introduce our new system, discussing how it improves auditory navigation for DJs and introduces new performance possibilities. We also discuss the role of haptics in an auditory display.

1. INTRODUCTION

A modern Disc Jockey (DJ) show consists of the DJ mixing portions of numerous vinyl records together with two turntables and a mixing board to combine sounds into a new unified song.

D'Groove has moved that setup into the digital realm so DJs can still work with a familiar interface but avoid dealing with numerous cumbersome records and explore novel performance possibilities.

As with most musical applications, D'Groove has strict requirements for cross-modal simultaneity. Levitin found that in order for a coupling to exist between physical motion and a resulting sound, the latency between manual inputs and auditory display must be perceptually zero and realistically 10 msecs or less [7]. One of the key challenges in developing D'Groove has been achieving this level of input-display latency, particularly given the jerky motions associated with the nature of the input.

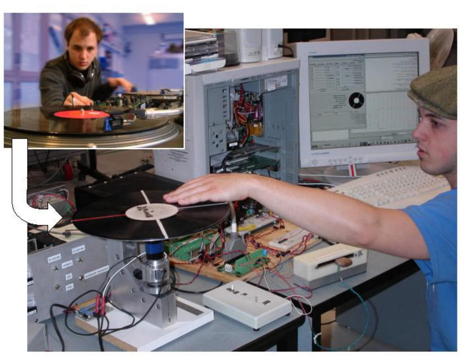

Figure 1*: A traditional DJ setup verses D'Groove.*

Our new DJ system incorporates haptics into the DJ's setup, enabling information to flow in both directions with the sense of touch. This also supports haptically augmented effects that a DJ can use in a performance, thus broadening the realm of DJ expression. Finally, we have improved the functionality of the turntable by providing visual queues to the DJ with a unique mapping system. In closing, we will discuss how our system advances the domain of the DJ promoting a new level of creativity.

1.1. Related Work

There are relatively few academic projects regarding DJ controllers as most of the research remains in the commercial sector and is therefore, unpublished.

The CDJ-1000 [8] is a CD player that is designed to emulate the turntable. While impressive, the CDJ-1000's turntable metaphor is incomplete because it lacks a motor. Thus, the unit does not rotate freely on its own and it loses out on the importance of rotation and the automatic progression of music.

Finalscratch [5], another commercial product, uses standard turntables and specially encoded records to send a signal into a computer. The system's shortcoming is that it does not provide a new means of control for DJs. They still perform as they would with a regular turntable and aside from permitting the DJ to access digital media, nothing more is gained.

In 2001, four students from Stanford, Keatly Halderman, Daniel Lee, Steve Perella and Simon Reiff, connected a turntable to a computer to control the playback speed of a song [11]. Their approach is similar to Finalscratch and thus does not support any new additions to the DJ domain.

Related to the study of turntable sounds, Kjetil Hanson is studying scratching sounds produced by turntable musicians [6]. This is of interest as it may enable us to produce new digital scratching sounds with our system.

More closely related to D'Groove, Lonny Chu is working on a haptic dial used to navigate audio in an editing scheme [1]. His application uses a dial to move linearly through an audio stream, while providing haptic feedback based on data in the audio.

1.2. The Tasks of a DJ

A DJ's primary goal is to entertain an audience by providing a musical experience, both auditory and visual. Today's DJs must be skilled in the art of mixing, where pieces of songs are blended together to create a coherent "symphony" of music. In order to mix music into a seamless stream, the first and most important skill a DJ must learn is "beatmatching", which consists of matching the beat structure of the forthcoming song with that of the one currently playing.

The turntable is a natural tool for this process as the rotational speed of the platter directly affects the playback speed (tempo) of the song being played on the platter, making it an intuitive “handle” for beatmatching. Turntable music comes in the form of vinyl records, physical artifacts that can be touched to alter playback speed and direction. Adjusting the phase of a forthcoming song to coincide with the phase of a currently playing song is done by using a hand to slow down, or even halt, the forthcoming song until its beats are synchronized with the current song. Currently, a DJ does this by using hearing for cueing and the hands to control tempo and phase. The DJ must listen carefully to the currently playing song in one ear and the forthcoming song in the other ear; then speed up or slow down the forthcoming song by physically adjusting the rotational velocity of the vinyl disk by hand until its beat structure matches that of the currently playing song. Once the two songs are beatmatched, the DJ can begin to mix the two into a seamless piece of music

Besides beatmatching, DJs also create unique sounds, known as scratches. A scratch is produced by moving the record back in forth in a rhythmic manner, thereby playing a sample of audio back and forth repeatedly. This is accompanied by cutting the sound on and off in different patterns to produce quick snippets of sound.

Turntables are the leading beatmatching and scratching controller for two reasons: 1) they provide a physical medium in which the DJ can touch the music and get a direct response in its playback speed and direction; and 2) they create a useful metaphor whereby the rotational movements of the turntable platter represents the progression of a piece of music. As a result, what might initially seem a trivial relationship is actually why turntables remain the leading controller for DJs. No other DJ controller provides a moving component and no other controller has lasted as long in the DJ domain as the turntable.

1.3. Motivation

Our goal when designing D’Groove was to enable a DJ to comfortably move to a digital format without losing the feel of a traditional setup. In doing so, we wanted to demonstrate some of the benefits of working with digital media over analog records, such as haptic force feedback, preservation of data, access to vast amounts of digital media not found on vinyl and musically intelligent controllers. Vinyl records become damaged with use and needles often skip when playing. We set out to improve on the methodology behind the turntable and make it an even more useful tool for the tasks of the DJ.

We wanted to make it easier for DJs to beatmatch songs. The basic paradigm was to link the rotational velocity of the turntable platter to the song’s tempo such that one revolution of the platter maps to n beats in a song (since we are primarily using modern 4/4 dance music, we choose $n = 4$). By placing visual cues on the platter, the DJ could then tell if two songs were beatmatched by noting that the markers travelled passed a corresponding point on each turntable at the same time. Figure 2 illustrates this idea with four turntables. When rotational velocity is coupled to the tempo of the song, we can visually see that the top two turntables are beatmatched. The lower left turntable is one beat out of phase with the top two and the lower right is half a beat out of phase. If the markers labeled 1 on each turntable pass by the markers labeled N on their respective turntable at the same time, we can say that the songs are beatmatched.

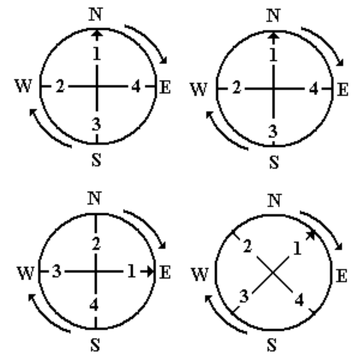

Figure2*: Markers on separate turntables help beatmatching with visual cues.*

2. D’GROOVE: THE DIGITAL HAPTIC TURNTABLE

The D’Groove system consists of both hardware and software components. The current external physical hardware portion of D’Groove employs three controllers: the turntable, the pitch slider and the queue slider. Sound is produced through a standard soundcard on a desktop computer. Our current prototype has only one turntable. A proper DJ setup would require two D’Groove turntables.

2.1. The Hardware

The DJ uses the turntable to control the playback of digital audio. A 14,400 counts per revolution encoder provides position values to our music player.

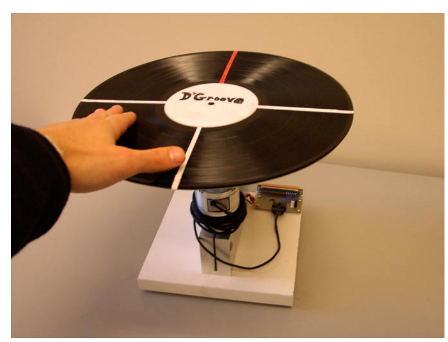

Figure 3*: The D'Groove Turntable.*

To control the desired velocity of the platter, the DJ uses a “pitch slider”. Its precision can be set in software and with a toggle switch, its range can be limitless. The DJ can set the slider to its maximum value, switch it off, reset the slider and switch it on again to further increase the motor speed in a manner similar to lifting a mouse and repositioning it to increase its “reach”. In future versions of D’Groove, we will accompany this slider with a continuous encoded knob which will set the base speed and avoid the use of a toggle switch.

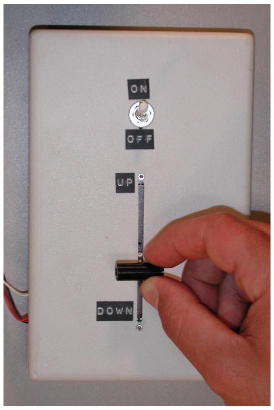

Figure 4*: The Pitch Slider.*

D'Groove's third component, the queue slider, consists of a sliding potentiometer - like the pitch slider, but in this case it is motorized. The motor is fitted with a 400 count encoder and is interfaced in the same manner as the turntable.

The queue slider replaces the functionality of the needle on a conventional turntable by relaying the current position. The length of the song is mapped to the length of the slider and the position of the handle indicates the temporal position within the song. The slider moves automatically along the track and when the user squeezes a pressure sensor on the slider's handle, we disengage the motor, allowing the user to freely relocate the handle. While moving the handle, the user feels position-based haptic feedback based on the track's content, until the handle is released and the song continues to play.

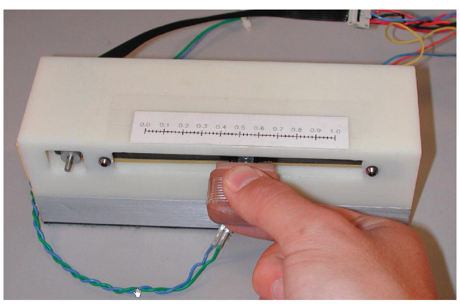

Figure 5*: The Queue Slider.*

2.2. The Software

D'Groove utilizes a real-time motor control and musical playback system. It uses two haptic control loops to invoke forces over two motors which control the motion of the turntable, as well as an audio engine to play digital audio at rates controlled by the turntable.

The motors are controlled via a PID controller on velocity. We sample the position of the motors at 1KHz and use that information to derive a force command for the motors on the next time step. The position of the turntable is read from the position encoder at a rate of 1KHz and stored in shared memory. This allows for rotation speeds as low as 1000/14400 rps = 4.17 rpm before aliasing occurs, which is well below usable speeds.

A graphical user interface allows the user to select various modes for the turntable, such as regular turntable mode, spring mode, bumps for beats or muddy patches (see Section 3 for more details). Within each mode, the user can alter various controller parameters, such as spring forces and damping. The user can also alter the PID parameters and get feedback on the current position and velocity of the turntable.

To minimize latency, we chose the real-time operating system RTLinux [9] for development. This is a free open-source OS that can be installed on top of most Linux kernels. The motor control loops and the position encoder loop are run as real-time components in the kernel and communicate with user level processes through shared memory. For data acquisition we use COMEDI [2], a generic API for use with multiple data acquisition boards, which allows us to write board independent software.

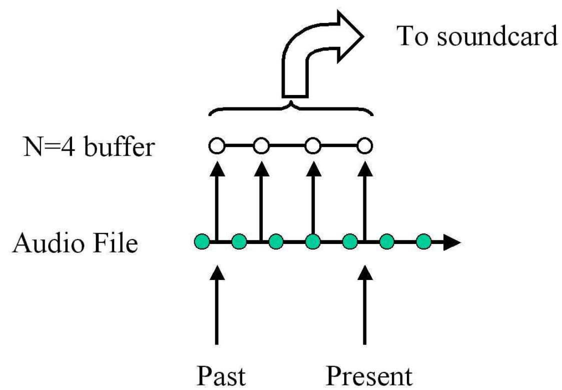

Figure 6*: A buffer of size N=4 is computed from the past and present pointers into an audio file, which are obtained from the turntable. The sample points are indicated by circles. The sample values in-between the samples in the audio file are computed by linear interpolation.*

The audio software was written in JASS [4], a unit-generator based audio synthesis programming environment written in pure Java. It streams an audio file and reads the encoder data (read from shared memory through the JNI, the Java Native Interface) at a fixed control rate of $F_c = N/F_s$, where N (currently 128) is an internal buffer size and F_s is the audio sample rate (currently 44100Hz). From the current and previous position of the turntable encoder data, a past and present pointer (we can think of this as the virtual needle) into the audio file is computed, which identifies the fragment of audio to be played. An audio buffer of length N is constructed by resampling this fragment. For example, if the turntable is moving at 0.7 of the normal playback rate, the needle will have moved by $0.7N/F_s$ seconds, which corresponds to 89.6 samples. If the past position of the needle was 12.3 for example, this means we have a segment [12.3-101.9] of the audio file which we now resample with N=128 sample points. We use linear interpolation for the in-between sampling. This is the same technique used for the generation of scraping and rolling sounds as described in [3]. Note that speeding up the audio will introduce aliasing. At present it is not clear if this produces an audible effect during scratching, and if so if the effect is desirable or not. The procedure is illustrated in Figure 6.

After computing an audio buffer of length N, it is sent to the audio hardware for playback. The latency of the audio playback is given by N/F_s = 3ms. This is achieved by using JNI to access the audio hardware as the current JavaSound implementations have very poor latency. For this the RtAudio [10] interface is used internally by JASS.

The audio processing algorithm is efficient and uses only a few percent of the processor on a typical 1GHz computer.

3. New Performance Possibilities

The use of haptic feedback in the turntable and the queue slider allows a wide variety of novel creative effects. D'Groove supports various modes to switch between the different haptic models. Some modes are exploratory and sometimes we do not use the motor to rotate the platter, but control it entirely by touch.

We can produce bump like feelings on the turntable by sending it varying amounts of current with respect to its position. We can control the height and number of bumps around the turntable as the user moves the platter. Each bump can correspond to a beat in the song, enabling the user to feel the beat structure as the platter is moved.

We can create new scratching techniques. By modeling a rotational spring on the turntable, the DJ is able to pluck at the platter instead of scratching it back and forth. The music plays back and forth along with the spring actions, sounding either very much like professional fast scratching, or – with different model parameters – like something that couldn't be done on a conventional DJ system. This also leads to automatic scratching, freeing up a hand so it can be used for other functions, like adjusting equalizer levels.

By altering the damping forces, we can vary the resistance felt by the user as the platter is rotated manually. The amplitude of the song is mapped to the friction applied to the turntable so that heavily damped "muddy" spots can correspond to musically "heavy" (or frequency rich) moments in a song. Lighter musical moments (breaks) can be accompanied with less damping on the turntable motor. Thus the user can feel musical events in the song when in this mode.

4. Conclusions and Future Work

With a tight coupling between turntable movements and musical playback, we are confident that we have created a unique and expressive tool for DJs to mix and scratch music. The haptics adds a new level of sensory inclusion and binds more of the user's abilities with the tool. Computer controlled turntable movements (like springs) allow for automatic procedures to be executed, allowing the DJ to focus on other tasks. The link between the tempo of the song and the rotational velocity of the platter creates a powerful bond between the interface and the music. This helps alleviate the beatmatching problem by making the rotational movements of the platter match the rhythmic structure of the song. Plus, we can now bring thousands of songs to DJ events, or even download them on site, and never damage a record.

Besides DJing, D'Groove could be useful for exploring data spaces that have been sonified. Its interface, with haptics, provides information about how certain sounds feel.

In future research, we would like to find a way to project virtual grooves on the turntable platter so DJs can get a visual indication of their music from the platter. Creating the grooves on a nearby monitor is easy but we feel that this information needs to be contained within the unit itself.

We also plan to perform user studies to establish the effectiveness of various modes of haptic feedback, and to determine the sound quality of D'Groove compared to a conventional DJ system.

To summarize, D'Groove is significant for the following reasons:

1) It is interactive and performance driven.
2) It combines the user's senses of touch, sight and sound for a multi-sensory experience.
3) It adds a new channel of information and communication for the user.
4) It allows DJs to access digital media while preserving the tactile aspect of turntables.
5) It improves on the relationship of the turntable platter and the progression of music.
6) It promotes new ways of scratching and new levels of creativity.
7) It is highly entertaining and fun

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